PAPER AAS 93-656

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Daniel T. Lyons
William L. Sjogren
Robert E. Lock
Rick S. Austin

Jet Propulsion Laboratory
California Institute of Technology
Pasadena, CA 91109

AAS/AIAA Astrodynamics Specialist Conference

VICTORIA, B. C., CANADA AUGUST 16-19, 1993

MS Publications Office, P.O. Box 28130, San Diego, CA 92198

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Beyond Aerobraking: Designing the Magellan Global Gravity Experiment

by

Daniel T. Lyons[1]
William L. Sjogren[2]
Robert E. Lock[3]
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The orbit of the Magellan spacecraft was circularized during a 70 day aerobraking phase, which ended on August 3, 1993. Shrinking the orbit apoapsis from 8467 km down to 541 km was required to obtain meaningful gravity science data at high and moderate latitudes. Aerobraking was the only way to reach this nearly-circular orbit, since the amount of propellant on board Magellan was at least an order of magnitude too small to circularize propulsively. This paper will describe the gravity science experiment which drove the final design of the nearly-circular orbit. Magellan is currently in a 541 by 197 km altitude orbit around the planet Venus.

This paper will also briefly describe the Magellan mission history, and then describe the design tradeoffs which went into picking the desired nearly-circular orbit.

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[1] Member of the Technical Staff, Jet Propulsion Laboratory, California Institute of Technology, M.S. 230-260, 4800 Oak Grove Dr., Pasadena CA 91109. (818) 393-1004.

[2] Magellan Gravity Principal Investigator, Jet Propulsion Laboratory, California Institute of Technology. M.S. 301-150. (818) 354-4868.

[3] Magellan Mission Planning Team Chief, Jet Propulsion Laboratory, California Institute of Technology, M.S. 230-260, 4800 Oak Grove Dr., Pasadena CA 91109. (818) 393-0811.

This paper presents the results of one phase of research carried out at the Jet Propulsion Laboratory, California institute of Technology under contract with the National Aeronautics and Space Administration.

Magellan Mission Description

I-he Magellan Mission is almost over. The primary mission objective to map the surface of Venus has been completed, with 99% of the surface imaged at least once by a Synthetic Aperture Radar (SAR), which doubled as a radiometer. A second antenna mapped the altimetry of 98% of the surface in parallel with the SAR imaging. The plane of the Magellan orbit remains nearly inertially fixed while the planet rotates beneath periapsis once every 243 days. Three 243 day mapping cycles were devoted to the radar experiment, so some regions have been imaged three times at different incidence angles. No further radar data will be collected due to telecom problems. The fourth 243 day cycle was devoted to mapping the gravity field. F'eriapsis was lowered into a ±6 km zone centered on 175 km for the Cycle 4 gravity map. This periapsis altitude was so low that atmospheric densities could be measured by both the navigational tracking and the attitude control perturbations. Although gravity data can be obtained from the entire orbit when the Sun geometry permits, the elliptical orbit geometry limits the high resolution gravity data to a ± 30° latitude band centered on periapsis. The periapsis latitude of the pest-aerobraking orbit will begin near the prime mission value of 10"N, near the descending node of the orbit. Obtaining a global, high-resolution gravity field is essential for understanding the internal geophysics of Venus.

Table 1: Representative Orbital Element Samples relative to Venus Mean Equator of 1985 IAU Ref.

		Start of Cycle-1 SAR Mapping	Start of Cycle-4 Equatorial Gravity	Post **Aerobraking** Global Gravity
Epoch		August 24, 1990	September 14, 1992	August 10, 1993
Semi-Major Axis	(km)	10,425.045	10.384.842	6,414.5
Eccentricity		**0.391795**	**0.399857**	**0.025333**
Inclination	(deg.)	85.5°	85.5°	85.5°
Node	(deg.)	-61.4°	-61.7°	-61.8°
Arg. **Perl.**	**(deg.)**	170.4"	169.3°	169.0°
Apoapsis AIL	**(km)**	8,458.5	8,486.3	525.0
Periapsis Alt.	(km)	289.6	181.4	205.0
Period	(seconds)	11,734.1	11,666.3	5,663.4

The Magellan spacecraft is currently in a nearly-circular, 94.5 minute orbit around Venus. The initial orbit is still inclined 85.5° to the Venus equator, which make the entire surface visible, to the spacecraft radar at some time during the mission. Now that the orbit is nearly-circular, Venus gravity will drive the latitude of periapsis much further north and south (+28° N to +4° N) than during the prime mission when periapsis could only drift by one or two degrees from 10° N. The periapsis altitude fluctuations will also increase from 15 km per cycle for the prime mission to 75 km for the post-aerobraking orbit. Although the nodal precession also increases for the post-aerobraking orbit, the node decreases by less than a degree per cycle even for the post-aerobraking orbit. During the recently completed 70 day Aerobraking phase, aerodynamic drag lowered the orbit apoapsis by 113 km per day, while periodic maneuvers maintained the periapsis in a 2 km corridor which gradually decreased from 140 km to 136 km. (Ref. 1 & 2) Aerobraking was terminated by raising periapsis to 197 km using a series of five 14.5 km maneuvers, Gravitational perturbations will quickly pull periapsis back down into a ±20 km corridor centered on 175 km.

The minimum period of the circular orbit was constrained by a power requirement to fully recharge the batteries during the long, frequent solar occultations. The solar panels were sized for the primary-mission mapping-orbit, where the time available for recharging was a much larger fraction of the orbit.

High Resolution Global Gravity Science Mission Objectives

The purpose of the Magellan high-resolution global-gravity mission is to map the global gravity field of Venus, especially at the high latitudes which were poorly resolved during the Cycle 4 gravity mapping phase. The global gravity mission phase began August 3, 1993, and will continue until nearly global coverage is achieved in mid-October, 1994. More than a full 243 day cycle is required to obtain the global gravity because Superior Conjunction and occultations of the Earth by Venus put gaps in the data. References 3 and 4 describe Venus gravity fields which have been produced using Magellan and Pioneer Venus Orbiter data. Even newer models are in use by the Magellan project. Once all of these Venus gravity data sets are combined and correlated with the topographic maps produced from the Magellan altimetry and Synthetic Aperture Radar data, geologists and planetologists will be able to infer the types of interior processes, such as isostatic adjustments to loads, dynamic support, and other interior processes which may be related to various surface features (Ref. 4). Venus gravity anomalies have been shown to be highly correlated with Venus topography (Ref. 5). The higher resolution, global gravity data set which will be obtained from the post-aerobraking phase will significantly increase the ability of scientists to correctly model mantle convection and lithospheric compensation mechanisms which modify the surface features on Venus (Ref. 6,7, 8).

Experiment Description

The gravity data are obtained by monitoring the coherent two way radio link between the spacecraft high-gain antenna and the Deep Space Network (DSN) tracking station. The uplink frequency provides a very well known reference for the downlink frequency. Small, local accelerations of the spacecraft can be inferred from the signal observed at the Deep Space Network tracking stations by comparing the sampled doppler shift of the downlink with the expected doppler shift. The expected doppler shift accounts for the gravitational accelerations of a spherical Venus, the Sun, the other planets, aerodynamic drag, the relative motions of Earth and Venus, the rotation of the Earth about the North Pole, tropospheric and ionospheric delays, and relativity. The raw tracking data are used as the observable in an orbit estimation. The residuals from the estimation process are small velocity variations, The line-of-sight accelerations are obtained by differentiating a spline fit of the velocity residuals. These small accelerations are attributed to the local nonuniformities in the gravitational field of Venus. Models of the surface mass distribution or density can be developed to reproduce the observed tracking data,

Mission Constraints

Two opposing constraints drove the design of the post-aerobraking gravity-mapping orbit: science goals and operational limitations. Science desires the highest possible resolution in the data. Since gravitational force decreases as the inverse-square of the distance, the gravity experiment becomes more sensitive to the small changes in gravitational acceleration when the spacecraft is closest to the mass variations near the surface. Because the size of the mass distribution cell which can be inferred from the gravity experiment is approximately equal to the altitude of the orbit, the gravity experiment requires the lowest possible orbit. The highly elliptical pre-aerobraking orbit limited the best data to a band centered on periapsis, while the current nearly-circular orbit enables global gravity observations. Figure 1 illustrates the effects of altitude on the quality of the gravity data for a simulation of the line-of-sight acceleration due to the local gravitational field for three different orbits:

1) a 280 by 8500 km elliptical orbit (the pre-aerobraking orbit),
2) a 250 km circular orbit (representative circular case), and
3) a 150 km circular orbit ("lower bound" case).

The post-aerobraking orbit is not perfectly circular, while the simulated data in Figure 1 include two perfectly circular and one highly elliptical orbits. Near periapsis, the post-aerobraking orbit can be as low as 155 km and will average 175 km and the sensitivity to mass variations will be similar to the 150 km circular simulation. Near the North Pole, the altitude will average 310 km so the sensitivity will be more like the 250 km simulation. Near the South pole, the altitude will average 400 km. Although the sensitivity of the post-aerobraking orbit still decreases as the altitude increases away from periapsis, the altitudes at the poles are nearly an order of magnitude better than the 2,130 and 3,298 km altitudes at the north and south poles during the cycle-4 gravity phase.

In Figure 1, sixteen identical negative or positive mass concentrations were placed along the ground track at the following latitudes: -60°, -50°, -40°, -30°, -20°, -10°, 0°, 5°, 10°, 15°, 20°, 30°, 45°, 50", 60°, and 65°. Each mass concentration is equivalent to a 300 km diameter, 1 km thick disk.

(Each disk spans 2.8° of latitude.) The negative mass disks give a negative line-of-sight acceleration difference, and represent "missing" mass equivalent to a 1 km deep crater. The positive mass disks give a positive line-of-sight acceleration difference and represent "additional" mass equivalent to a 1 km high mountain. Zero acceleration difference would be experienced if Venus were homogeneous (which it is not) and spherical (which it nearly is). The added or subtracted surface mass has the same density as the average surface material (3 grams/cubic-centimeter). The simulated orbit is viewed edge on, so the accelerations correlate directly with mass variations along the ground track.

Near periapsis (+10° latitude), the elliptical (solid line) and the 250 km circular (thick, grey line) have very similar characteristics because the altitude of the elliptical orbit is only 38 km higher than for the 250 km circular. The elliptical case, which is representative of the pre-aerobraking orbit, is most sensitive near periapsis and becomes much less sensitive as the altitude increases away from periapsis. The lower right corner of Figure 1 indicates the latitudes of Ishtar Terra, a major feature on Venus. The figure indicates that the resolution of gravity perturbations associated with large scale surface features which exist at high latitudes will be significantly improved by a circular orbit. (The simulated data in the figure is for arbitrarily equal mass disks placed at different latitudes and does not attempt to actually model Ishtar Terra.) Information about the mass distribution of Ishtar Terra has important scientific implications.

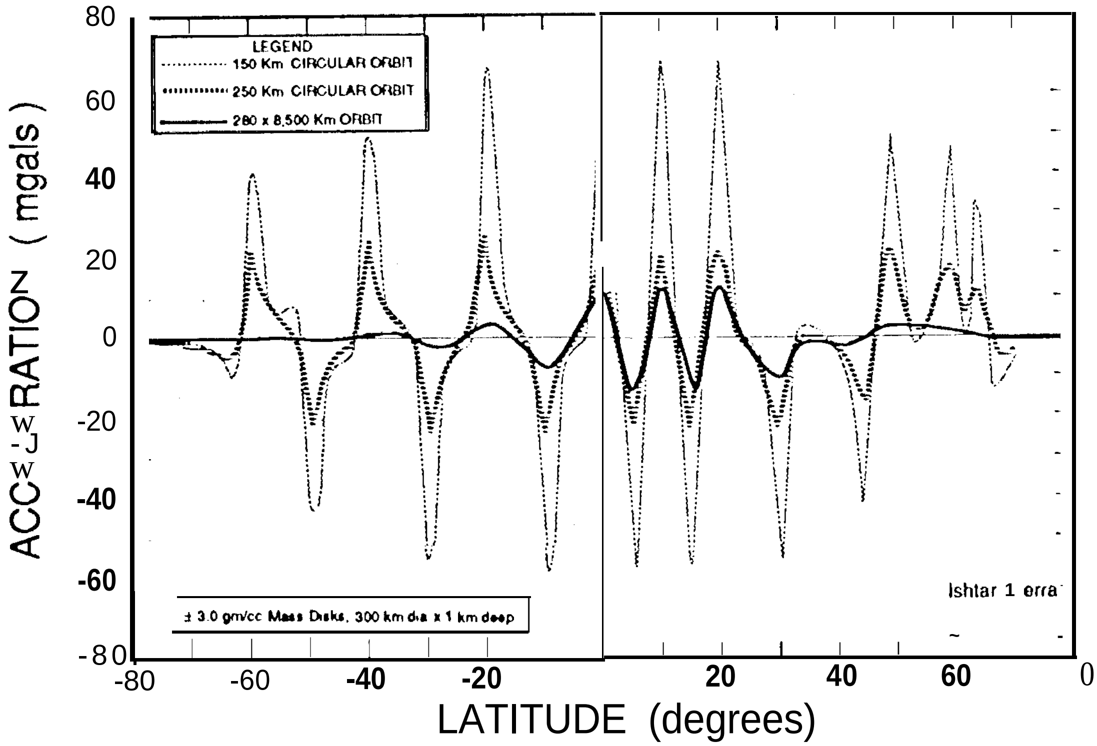

Figure 1: Simulated Line-of-Sight Accelerations for Edge-on Viewing

At higher latitudes, the 250 km circular case shows several interesting features which are barely noticeable or unresolvable on the elliptical case. The magnitudes of each of the peaks for the circular orbits are about the same at each of the identical mass concentrations, because the spacecraft altitude is constant for a circular orbit. There is a slight decrease in observed magnitude of the line-of-sight acceleration at the high latitudes because the viewing geometry is a function of the location of the spacecraft. The cluster of positive masses around 60° latitude shows the line-of-sight accelerations of several simulated mountains which are close together. Similarly, the pair of negative and positive mass concentrations at 45° N and 50° N shows the effect of a close pair of equal and opposite mass concentrations.

Unfortunately, reducing the apoapsis altitude also reduces the orbit period and increases the fraction of the orbit which can be occulted from the Sun. The fraction of the orbit available to recharge the batteries during the peak solar occultation became the most limiting. Because the solar panels were sized for a completely different orbit, the Magellan project is fortunate that the minimum orbital period which can be accommodated (94 minutes) is only slightly larger than the minimum possible period (90.5 minutes). High risk is acceptable during this final phase of the mission, so no margin is included for significant degradation of either of the two solar panels. Power cycling is not required for the planned post-aerobraking mission, so there are some options available should the panels degrade.

Keeping the dollar cost of the post-aerobraking mission below a very small cost cap also affected the design of the post-aerobraking orbit, Because the Magellan Project has so successfully met all of the objectives of the prime and early extended missions, funding for the circular orbit gravity mission will be a tiny fraction of the funding for the prime mission, This low funding level means that very few people will staff the project, so the number of maneuvers during the circular orbit phase must be small to minimize operational complexity, Since the gravity field tends to pull the periapsis lower at the rate of approximately 38 km per 243 day cycle for low altitude, nearly-circular Venus orbits, and since an uncontrolled periapsis would fluctuate by nearly 75 km, periapsis must begin at a relatively high altitude in order to avoid operationally costly maneuver planning, execution, and analysis. Some maneuvers are required to keep periapsis above the top of the atmosphere during the post-aerobraking gravity-mapping phase so that the initial periapsis altitude will be low enough to meet the science requirements. The goal was to find an achievable orbit which met the operational constraints imposed by the reduced workforce by minimizing the number of maneuvers while keeping the altitude as low as possible.

To further complicate the design, the thermal constraints which evolved during the extended mission as the thermal properlies of the spacecraft degraded had to be factored into the design of the sequence of events during an orbit. The darkened spacecraft surfaces absorb too much heat from the Sun. Some attitudes can only be maintained for relatively short intervals before the spacecraft must turn and hide from the Sun behind the large, solid high-gain antenna. Since the gravity experiment requires this same high-gain antenna to be pointed at Earth for X-band data collection, the sequence of events in a series of orbits must be carefully controlled to maximize the coverage of the planet while maintaining thermal control of the components. There is an S-band only medium gain antenna which, when used, also hides the spacecraft behind the high-gain antenna, as was done during the aerobraking phase. There are currently no plans to use the medium-gain antenna, since the S-band signal is much noisier than the X-band high-gain signal, however, a recently imposed requirement for the tracking arcs to be more than 45 minutes may result in some planned medium-gain attitudes in the future.

Magellan is a 3-axis stabilized vehicle. Inertial attitudes are propagated by integrating gyro data. In order to accurately point the high-gain antenna at the Earth, the gyros must be periodically calibrated by scanning a pair of stars with a V-slit star scanner which is rigidly mounted to the side of the spacecraft. A star scan requires a triplet of rotational attitude maneuvers which interrupt the gravity data collection interval. During mapping, the star scan always occurred at apoapsis. As the orbit shrank during aerobraking, Venus blocked more and more of the stars from view at apoapsis, and the location of the star scan had to move to different locations in the orbit in order to view the only available star pair. (In fact, the end of the aerobraking phase was linked to the time when only available star pair required a star scan location which overlapped the part of the orbit when the spacecraft had to be in the aerobraking attitude - we could choose to not aerobrake and do star scans, but could not choose to aerobrake without star scans.) During the prime mission when the star scan occurred at apoapsis, a single star pair was all that was available. Now that the orbit is nearly-circular, not only is the star selection usually limited to a single pair of stars, but the location of the star scan must move to different locations in the orbit in order to see that single star pair. Solar considerations limit the visibility of different star pairs at different dates, forcing periodic changes in the acceptable star pairs. Thus, the required star scans not onfy require time from the orbit to maneuver the spacecraft away from earth pointing, but the location of the star scan in the orbit must change periodically and may overlap with a location where gravity data is desired. The movement of the star scans combined with the changes in the thermal constraints and the location of the Earth and Sun occultations during the orbit, require periodic changes to the sequence of events in the orbit. Low cost operational considerations will limit the number of changes to the sequence to those essential for survival rather than those which might optimize the data quality or quantity.

The following figures illustrate several aspects of the nearly-circular orbit design. The plots show what activities must occur during a pair of orbits and how an initial 525 x 200 km orbit is expected to evolve overtime based on the 21x21 MGN5 gravity field, and including five 3.2 m/sec maneuvers to keep the dynamic pressure below the 0.0008 N/m^2 constraint. The MGN5 gravity field was derived from the first 3 cycles of Magellan tracking data and from Pioneer Venus Orbiter tracking data. The actual 541 x 197 km orbit achieved by Magellan following the successful completion of Aerobraking is very close to the planned 525 x 200 km design target described below.

1 he sequence of events alternates between the activities shown in Figure 2 for a pair of orbits early in the post-Aerobraking phase. Starting at the "Orbit Boundary" of orbit #1 where the star's are scanned near the descending node relative to the Venus equator, and moving clockwise with the motion of the Magellan spacecraft, the following sequence of events is followed:

- Scan Stars to update attitude knowledge,
- Turn HGA to Earth and collect doppler data,
- Turn to the hide attitude near apoapsis on Orbit 1,
- Turn HGA to Sun and hide behind the High-Gain antenna dish,
- Turn the High-Gain antenna to Earth and collect doppler data
- Switch to Orbit #2 at the orbit boundary,
- Turn to the hide attitude by the south pole and hide behind the High-Gain antenna dish,
- Turn the High-Gain antenna back toward the Earth for doppler collection,
- Switch back to the star scan on orbit 1 and start the process all over again . . . .

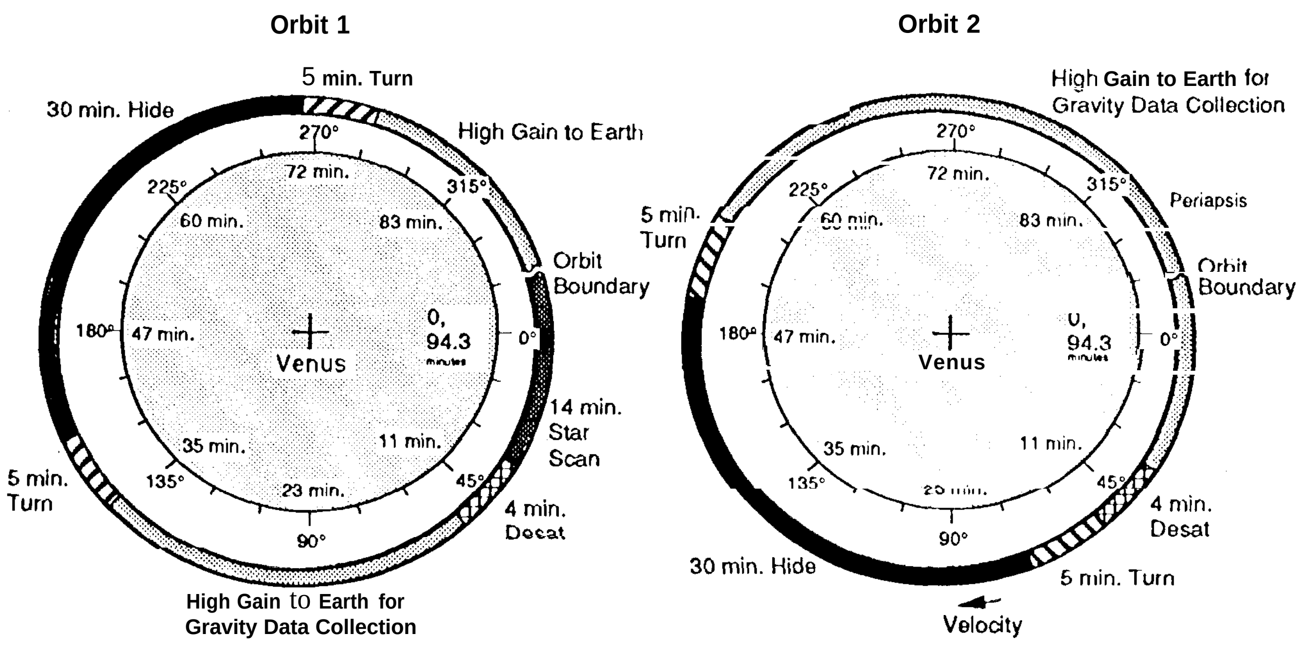

Figure 2: Sample Two-Orbit Sequence of Events

The doppler data collection interval is shorter than the time when the high-gain antenna is pointed at the Earth because several minutes are required to establish a two-way link and because part of the orbit is usually behind Venus. (An even more limiting constraint is that the Deep Space Network must allocate one or more antennas to transmit and receive - there is no way to record gravity data on-board, so there is no data if no one is listening in real-time. Since Magellan is not the only user and is late in the extended mission, obtaining DSN coverage is extremely difficult.) The sequence of events shown in the orbits must change whenever the location of the star scan moves to a different location on the orbit. The star scan location shown is for the first phase of the post-aerobraking gravity mission. The two hides are at different locations in the orbit in order to enable nearly global coverage. The hide periods will be replaced by high-gain antenna to Earth whenever possible due to favorable Sun-Probe-Earth angles and solar occultation intervals.

Figure 3 shows the Sun-Earth-Probe and Sun-Probe-Earth angles versus calendar date, and illustrates two additional constraints. When the spacecraft goes through superior conjunction, the communication link between the spacecraft and Earth becomes very noisy. Commands cannot be reliably sent to the spacecraft. Maintaining the two way link for gravity science cannot be guaranteed. Thus, a gap in the gravity data may be expected around superior conjunction. (Of course there are scientists who will use the "noisy" superior conjunction data to study the plasma generated by the Sun, so some useful data will be collected.) The other constraint is that the most financially optimistic projection for the end of data collection is currently October 31, 1994, which coincidentally falls on top of the next inferior conjunction. Dates when the periapsis is behind Venus as viewed from the Earth are also noted on this and subsequent figures. The spacecraft must hide behind the high-gain antenna for some fraction of the orbit whenever the Sun-Probe-Earth angle is within 60 degrees of 90 degrees when there is no solar occultation or within 45 degrees of 90 degrees when the solar occultation is more than 30 minutes. Because long tracking arcs using the high-gain antenna are desired, the thermal team is presently analyzing the effects of shortening the hide durations whenever possible, and is even considering raising the acceptable thermal limits (redlines) to maximize the length of the tracking arcs. A 90 degree Sun-Probe-Earth angle means that the Sun shines directly on the side of the spacecraft when in the high-gain to Earth attitude required for gravity data collection and overheats some of the equipment bays, especially the Command and Data System computer.

Figure 4 shows the Magellan orbital period versus date. I-he period of the orbit always remains above the 94 minute constraint, in part because four 3.2 m/sec maneuvers are required to raise periapsis by 11 km to counteract the downward drift in the periapsis altitude from cycle to cycle shown in Figure 5. The actual change in speed, AV, for a 12 minute burn may be closer to 4 m/sec, since the Attitude and Articulation Control Subsystem used less than the allocated amount for aerobraking, so the tank pressure is higher and thruster performance is better than the worst case parameters used in this example. A fifth maneuver will be required if the mission continues beyond the scheduled end date.

The gravitational perturbations have a tremendous effect on the altitude of periapsis. The penapsis altitude drops by 45 km following the start of the circular gravity mission, reaching a minimum of 154 km near midnight local solar time. 1 he periapsis altitude rises to a peak of 195 km (including a 11 km periapsis raise maneuver) by noon, local sofar time. Comparing the noon peak to the corresponding peak 243 days later (slightly after the next noon) and noting that the second peak is 5 km lower in spite of three more 11 km periapsis raise maneuvers shows that the periapsis altitude is drifting downward by 38 km per cycle. During this period, the minimum altitudes occur near midnight where the atmospheric density is lowest, and the maximum altitudes occur near noon where the atmospheric density is greatest. This fortuitous behaviour tends to smooth out the magnitude of the aerodynamic drag force and thus maintains an aerodynamic drag sufficiently large to enable atmospheric science data collection without increasing the number of maneuvers. Significant atmospheric science data was obtained during Cycle 4 at periapsis altitudes between 170 and 180 km. The average periapsis altitude for the nearly-circular orbit is also approximately 175 km.

The computer program, vpohop, used to propagate the trajectory was developed to simulate the Magellan aerobraking phase and is described in Reference 2. The four 11 km orbit trim maneuvers plus a fifth at the planned end of mission were automatically triggered by the program when the dynamic pressure reached a specified value of 0.0008 N/m^2, as illustrated in Figure 6. This dynamic pressure limit guarantees that the reaction wheels can be automatically unloaded by a scheduled desaturation once per orbit before an emergency desaturation is triggered by the on-board fault protection software.

Figure 7 shows that the orbital altitude at the closest approach to the North pole easily meets the 400 km altitude required to eliminate the need for the Kuala constraint to keep higher order harmonics in reasonable bounds when processing the data into a global gravity field. Because the orbit periapsis is in the Northern hemisphere, the altitudes at the south pole are about 90 km larger

525 x 200 Km initial Nearly Circular Magellan Orbit

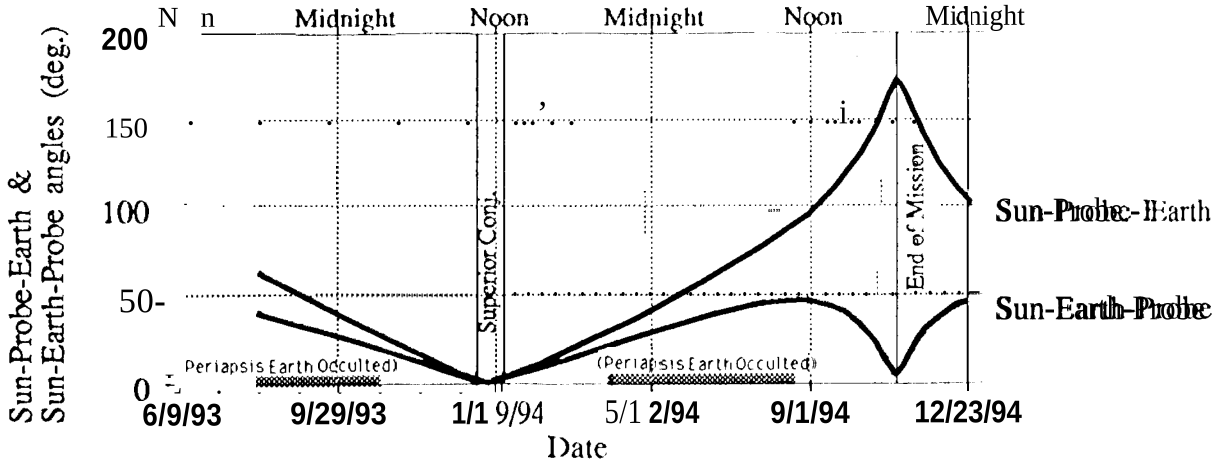

Figure 3: Sun-Probe-Earth & Sun-Earth-Probe angles

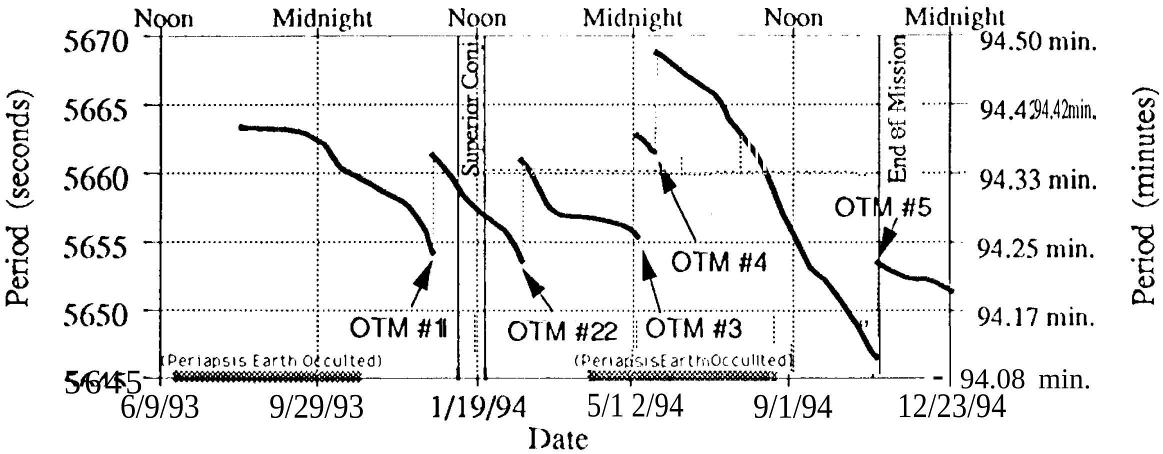

Figure 4: Period

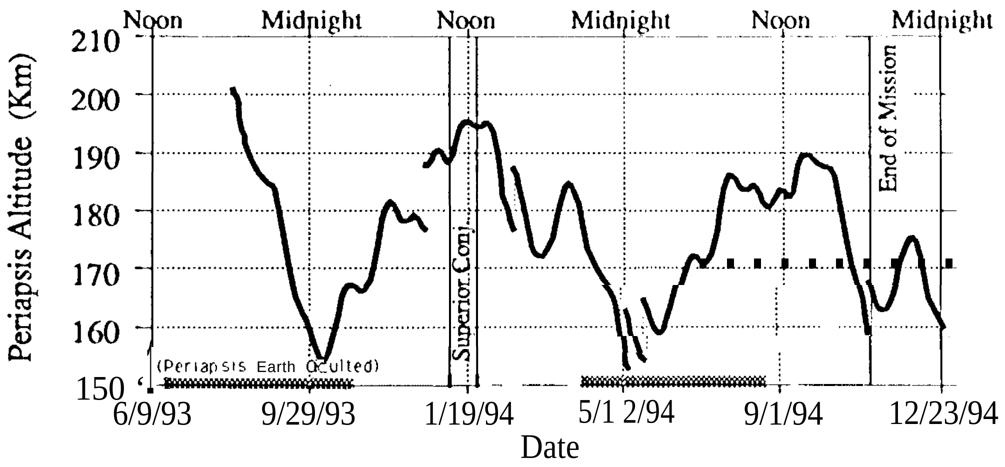

Figure 5: Periapsis Altitude

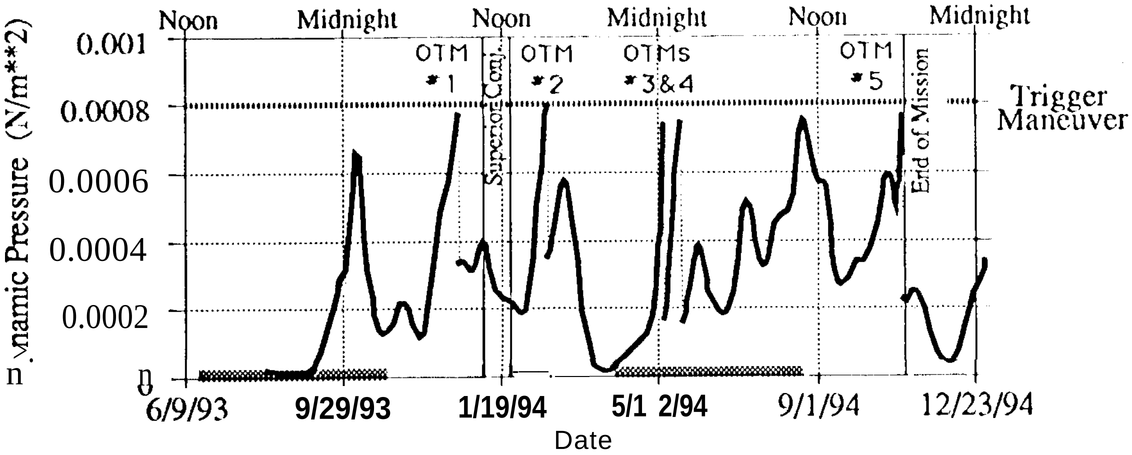

Figure 6: Dynamic Pressure

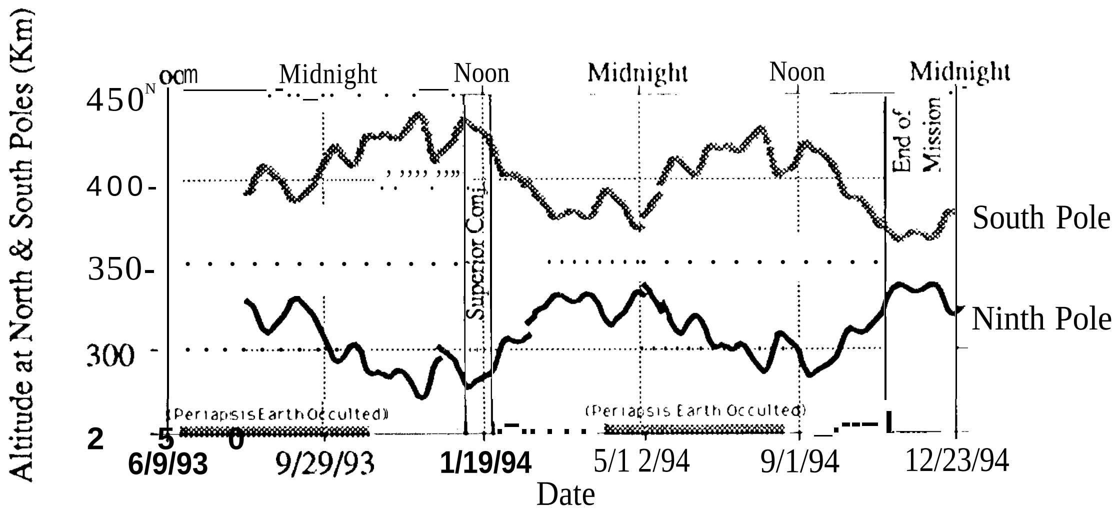

Figure 7: Altitude at North & South Poles

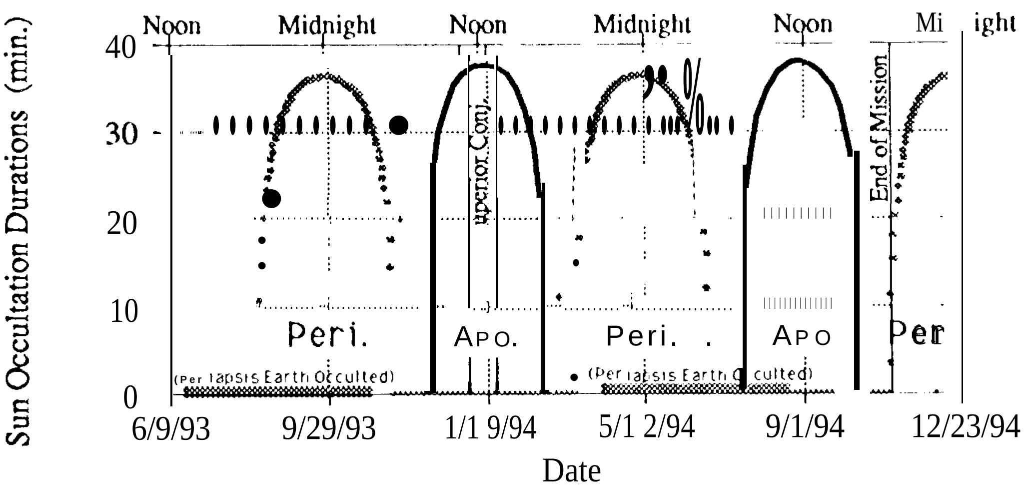

Figure 8: Sun Occultation Durations

than at the North pole. The average value at the South pole meets the 400 km requirement and is acceptable to the gravity science principal investigator. The changes in altitude near the poles are nearly equal and opposite because the altitude changes are driven by the large changes in periapsis latitude, which helps one polar altitude at the expense of the other, rather than by the changes in periapsis altitude, which change both polar altitudes in the same direction. Careful inspection of Figure 7 reveals small jumps in the curves which correspond to the 11 km periapsis raise maneuvers. The highest altitudes over the south pole correspond to dates where the most interesting regions are in the north, where the altitude is lowest due to the northerly latitude of periapsis.

Figure 8 shows the durations of the solar occultations at apoapsis and periapsis. Because the spacecraft is much closer to the planet than during the prime mission, there are few times when the spacecraft is not occulted from the Sun. The batteries will be reconditioned during at least two of these non-occulted periods. If the panels degrade more than is expected, then extreme measures to shut off all non-critical equipment during the occultations may be required. Power cycling the hardware is extremely undesirable, since power cycling reduces lifespan.

The goal of the gravity mission is to obtain a global gravity map. Since a full 360 degrees of longitude of equatorial data was obtained during Cycle 4, the prime objective of the post-aerobraking mission is to obtain data at the higher latitudes. In addition to gaps in the DSN tracking coverage, holes in the gravity data are caused by superior conjunction gaps, periapsis occultations of the Earth, and hides to prevent overheating by the Sun, Apoapsis occultations are not quite as important because the altitudes on the apoapsis side of the orbit are above the 400 km requirement. Figure 9 shows that the superior conduction produces a gap in the data for longitudes from 320° to 350°, when the orbit is passing over the very interesting region known as Ishtar Terra. These longitudes are crossed again one cycle later, slightly after noon but before the optimistic end of mission. (Local Solar Noon at periapsis occurs every 225 days, while the planet rotates beneath penapsis every 243 days.) Figure 10 shows that the second noon occurs when periapsis is not occulted, so it will be possible to fill in the superior conjunction gap if the spacecraft is still operational. Unfortunately, superior conjunction puts a gap in the gravity data right in the middle of an interval when the Earth is visible at periapsis and hiding is not required, so long, high-resolution tracking arcs linking the poles would otherwise be possible.

Although periapsis is Earth occulted at the start of the circular mission, the project will have minimal DSN coverage during this period due to overlaps with Mars observer orbit insertion activities and Galileo flyby of asteroid Ida. Unfortunately, obtaining DSN coverage which meets the data collection requirement of 8 orbits per day will be extremely difficult until at least March of 1994 due to the view period overlap with other projects.

Because the plots end at the end of calendar 1994, it is not so obvious that the optimistic end of mission is scheduled for the middle of a very long period where periapsis will be visible for more than 360° of longitude. This unusually long period of periapsis visibility occurs whenever inferior conjunction coincides with a face-on view of the orbit (illustrated in Figure 11) and is highly desirable for producing a smoothly contiguous gravity map. The trajectory pole angle in Figure 11 is the angle between the line-of-sight from Earth to Venus and the angular momentum vector, which is perpendicular to the plane of the Magellan orbit around Venus. This angle is also extremely important for interpreting the observed gravitational signature,

The next two figures show the Periapsis Latitude and Penapsis Altitude versus the Longitude of the descending node relative to the Venus Equator. The longitudes of some of the major surface features are noted at the top of the figures.

The periapsis latitude has two distinct peaks near the geologically interesting regions known as Beta Regio and Ishtar Terra. Beta Regio lies between latitudes 15° and 30° North, exactly under penapsis. Fortunately, periapsis is not occulted during the first pass over Beta Regio, and may be barely visible following the second interval of Earth occultation at periapsis.

Although Ishtar Terra lies much further North (above 60° latitude), periapsis is also as far North as it will get due to the gravitationally induced drift in the latitude of penapsis, so the altitude over Ishtar will be as low as possible and the resolution of the gravity data will be very good. Unfortunately, superior conjunction coincides with the first pass over Ishtar. Maxwell Montes is adjacent to Ishtar, but

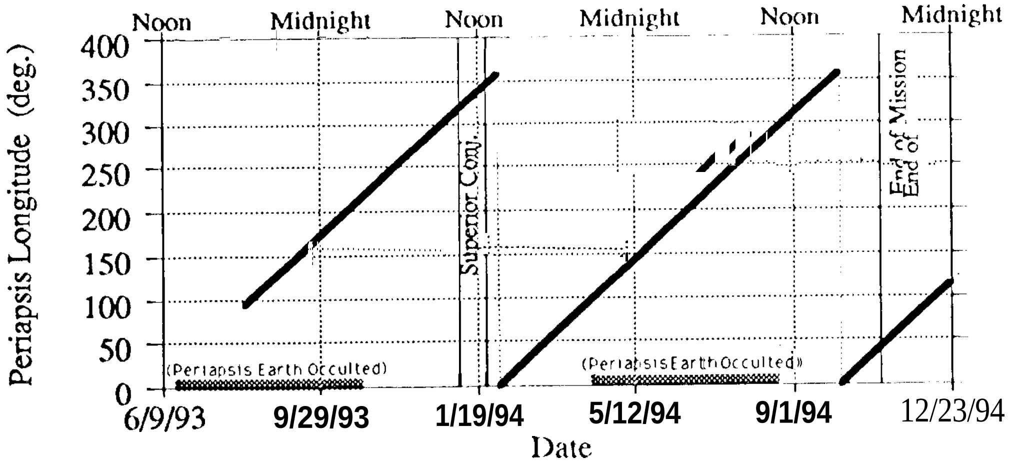

Figure 9: Periapsis Longitude

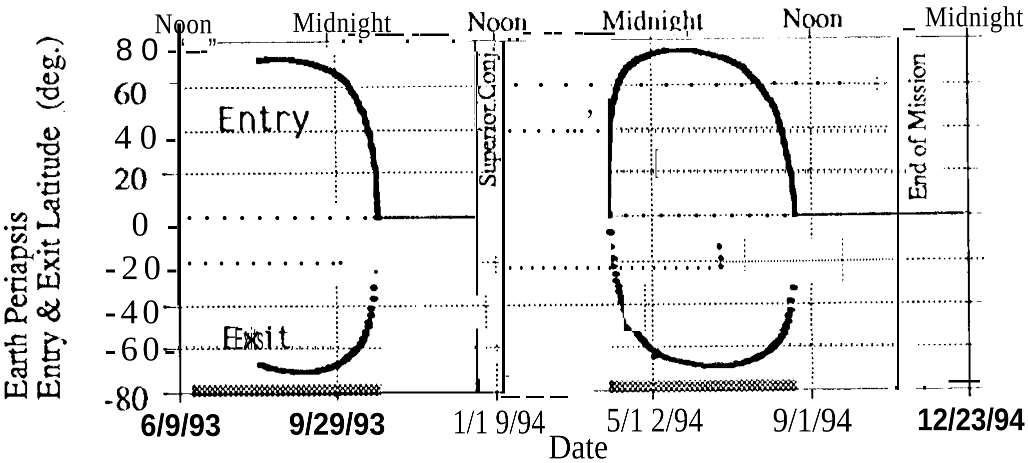

Figure 10: Earth Periapsis Entry & Exit Latitude

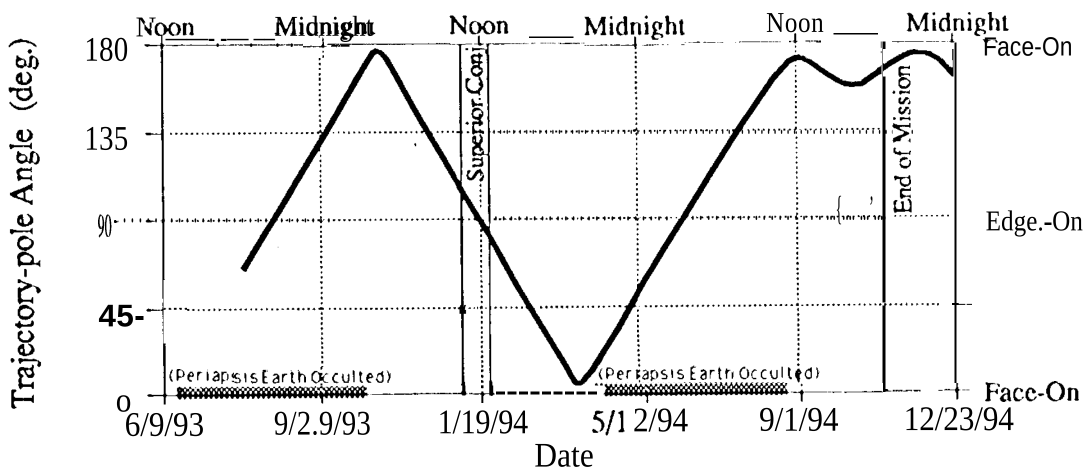

Figure 11: Trajectory-pole Angle

525 x 200 Km Initial Nearly Circular Magellan Orbit

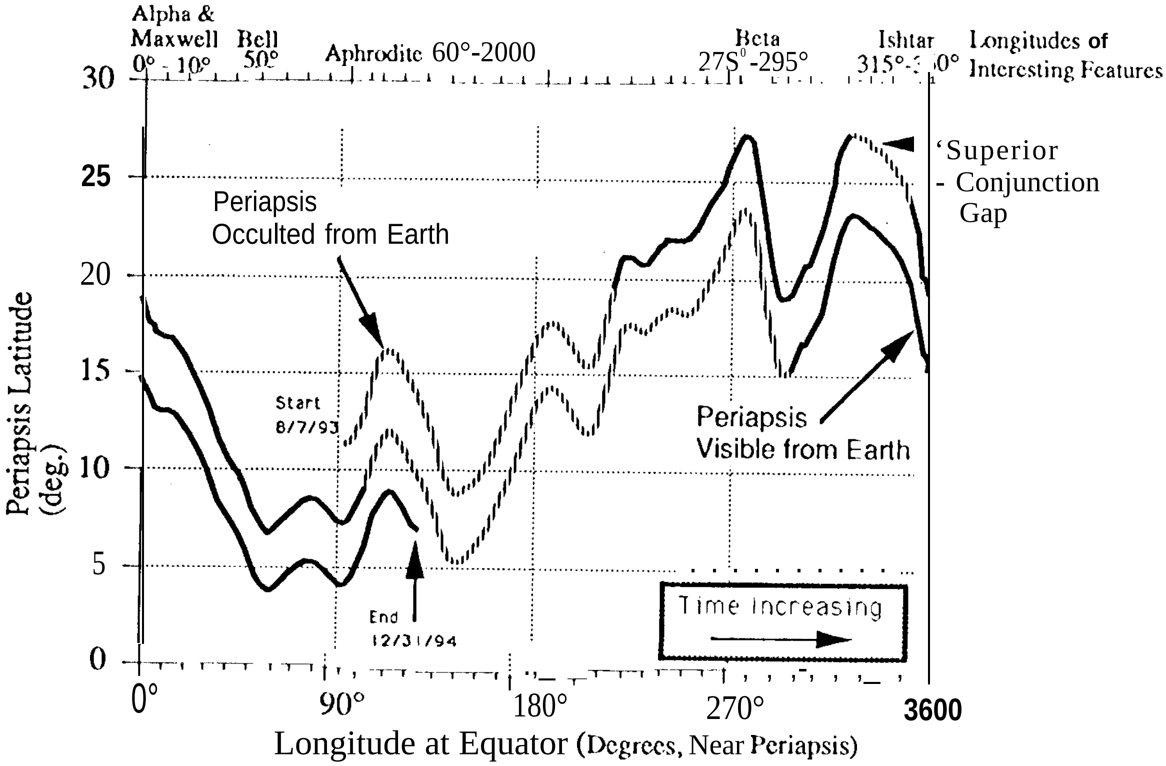

Figure 12: Periapsis Latitude versus Longitude

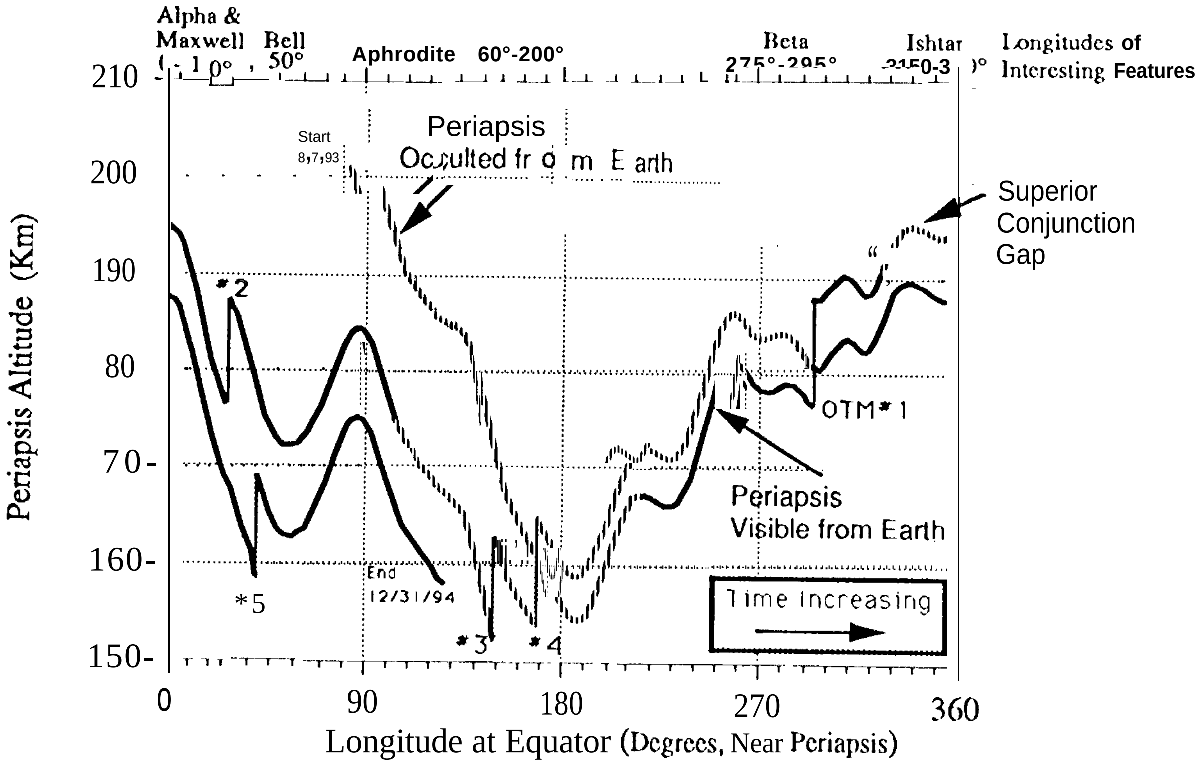

Figure 13: Periapsis Altitude versus Longitude

the periapsis latitude has decreased to about 15° by the time the orbit reaches Maxwell, so the altitude will be slightly higher than for Ishtar but will still be well below the 400 km constraint. Fortunately, observations of the range of longitudes containing Maxwell, Alpha, and Bell are not hampered by superior conjunction or Earth occultation.

Aphrodite lies in the southern hemisphere, just below the equator, Periapsis is at its southern most latitude over most of aphrodite, so the altitude will be a minimum. Figure 13 shows that the precipitous drop in the periapsis altitude occurs whenever periapsis passes close to Aphrodite. Unfortunately, the periapsis of the orbit is occulted for both of the first two passes over Aphrodite. The third pass is not occulted, but the mission is scheduled to end halfway through this third cycle, which if continued, would span more than 360° of longitude without any interruptions by periapsis occultations or superior conjunctions.

Conclusions

Obtaining a high resolution, global gravity field for Venus will significantly enhance the science return from the Magellan Mission by enabling geophysicists and planetologists to infer the interior geodynamics. Selection of the proper nearly-circular orbit was essential for maximizing the resolution of the data within the very limited resources which are available to the Magellan Project. Spreading several 3.2 m/sec maneuvers across the nearly-circular orbit phase maintained a low periapsis altitude, which maximized gravity science data resolution while enabling continuation of atmospheric science data collection. Other opportunities for collecting science data have been identified, and are being pursued on a best level of effort basis by the remaining members of the Magellan flight team.

Maximizing the science value of the data also required careful placement of events in the orbit in order to maximize coverage due to the thermal and attitude control requirements, while minimizing the number of labor-intensive changes to the sequence by a very shrunken flight team. The gravity mission described above will challenge the remaing members of the flight team, who are - as of press time - scrambling to modify the very first sequence to meet a new requirement for longer tracking arcs.

Acknowledgements

The authors wish to acknowledge the tremendous effort expended by the spacecraft team at Marfin Marietta Astronautics Group in Denver Colorado, the navigation and mission control teams at the Jet Propulsion Laboratory, and the Deep Space Network around the world during the aerobraking phase which made the high-resolution gravity experiment possible.

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